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THE INSTITUTE OF PAPER CHEMISTRY

Appleton, Wisconsin

CREEP BEHAVIOR OF BOXES AND CORRUGATED BOARD
PART I. VARIANCE ANALYSIS

✓Project 1108-30

Report Three

A Preliminary Report

to

Technical Division

FOURDRINIER KRAFT BOARD INSTITUTE, INC.

November 30, 1965

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CREEP BEHAVIOR OF BOXES AND CORRUGATED BOARD
PART I. VARIANCE ANALYSIS

SUMMARY

The study has for its purpose the development of information regarding the long-term load-carrying ability of corrugated board and boxes. This report summarizes a preliminary analysis of the differences in stacking life exhibited by the various box samples included in the study. Also, additional efforts to analyze the box creep curves are discussed.

The results to date indicate that

1. Certain of the box samples exhibit significantly longer stacking lives than other samples. The differences in stacking life can be quite large and, in an industrial environment, might be the difference between satisfactory and unsatisfactory performance. While the factors associated with long or short life are not known, their investigation is one avenue of approach to improvements in corrugated box performance.

2. The relatively long stacking times which are being obtained at the lower load ratios seem impractical from a test standpoint. With the completion of tests in progress, it is suggested that the lower load ratio tests be discontinued.

3. Further efforts were made to fit a power function equation of the following type to the deflection <u>vs</u>. time curves:

$$t = K_1 (D - D_6)^{K_2}$$

or $$\text{Log } t = \text{Log } K_1 + K_2 \text{ Log}(D - D_6)$$

where

t = time

D = deflection at time t

D_6 = box creep deflection at 60 minutes

and K_1, K_2 are constants

Creep life predictions were relatively poor using values for D_6 which were derived from the load ratio. Further work is needed in this area to determine if the above or other functions can be successfully used.

INTRODUCTION

It is well known that a corrugated box subjected to warehouse stacking will support only a small fraction of the box compression strength for a prolonged period. For this reason a study is underway to provide information relative to the warehouse stacking (creep) characteristics of corrugated boxes and board.

While the results are far from complete because of the long time intervals involved, the available data is being examined to explore the major data trends and methods of analyzing the data.

In Report Two it was noted that

1. The following average box failure lives were obtained from an analysis of the relationship between applied load and the logarithm of time:

Applied Load, ratio	Box Failure Life, days
0.70	11.5
0.65	32
0.60	92
0.55	260

2. The variability in box creep failure lives is large and seems to be explained, in large part, by the variability in conventional box compression tests.

3. Mathematical expressions to describe the box creep deflection *vs.* time curves were studied with the objective of estimating stacking failure times from short term tests. Preliminary results with equations of the following type were reasonably favorable:

$$t = K_1 (D - D_6)^{K_2}$$

where

t = time

D = deflection at time t

and D_6, K_1 and K_2 are constants

This report continues the study of the creep deflection vs. time curves and also discusses the significance of the differences in failure life exhibited to date by the various box samples.

DISCUSSION OF RESULTS

Box Failure Time and Deflection Vs. Applied Load

The creep failure lives and deflections for the boxes are summarized in Tables I and II and illustrated in Fig. 1. In the period since the last report only a few boxes failed. As one result, a number of the boxes have survived for extremely long periods of time -- over 500 days in a number of cases. Such long test intervals are impractical and it appears desirable to restrict future tests to load ratios of about 0.625 or greater.

Because so few boxes failed during the period since the last report, the regression line shown in Fig. 1 was not recalculated for this report. As discussed in Report Two, the results obtained to date exhibit considerably longer lives than expected on the basis of the work by Kellicutt and Landt (1). This comparison is shown in Table III:

TABLE I

SUMMARY OF BOX CREEP RESULTS

Applied Load Ratio	Specimen No.	Failure Time, days Sample 2406 A-200	Sample 2407 A-200	Sample 2408 A-200	Sample 2430 A-200	Sample 2456 A-175	Sample 2457 C-350	Sample 2497 B-200	Sample 2498 B-275	Sample 2510 C-275	Sample 2511 B-175
0.75	1	0.22	0.44	1.15		6.46	17.74		0.89	4.88	1.49
	2	0.47	32.08	1.21		4.16	9.36		2.46	13.89	3.27
	3	0.50	15.49	1.39		0.03	26.10		3.11	50.60	4.78
	4	0.32	0.70	1.07		0.24	153.20		6.22	10.39	0.16
	Av.	0.38	12.13	1.20		2.72	51.60		3.14	19.94	2.42
0.70	1	270.6	33.4			33.1	62.6	8.9	127.0	over 120	10.9
	2	19.6	40.6			132.7	243.2	53.8	15.9		3.6
	3	20.0	41.7			79.5	over 112	9.5	35.7		10.3
	4	4.5	15.2			47.6		4.0	35.2		18.6
	Av.	78.7	32.7			73.2		19.0	53.4		10.8
0.675	1	30.5	87.9								
	2	62.1	76.4								
	3	38.4	over 122								
	4	20.4									
	Av.	37.8									
0.625	1	33.8	15.8	16.5	29.8	115.4	72.6	19.9	248.3	over 139	62.6
	2	4.8	13.6	79.6	62.9	167.4	over 513	7.7	160.4		63.0
	3	155.7	95.9	13.1	90.1	over 513	200.6[a]	140.6	214.3		over 104
	4	115.4	93.8	2.6	over 512	over 514	405.8[a]	101.5	263.0		over 75
	Av.	77.4	54.8	28.0				67.4	221.5		
0.575	1	over 233	over 233			over 414	over 414	315.9	over 424	over 103	over 74
	2					over 287		over 103			
	3					over 233					
0.55	1	113.3	366.6	129.3		over 511					
	2	114.5	387.4	20.6		over 514					
	3	174.4	over 511	199.2							
	4	243.6		over 223							
	Av.	161.4									
0.50	1		344.0								
	2		578.0[a]								
	3		728.9								
	Av.		550.3								

[a] Survived two hours exposure to humidities as high as 80% R.H.

TABLE II

COMPARISON OF BOX CREEP DEFLECTIONS PRECEDING FAILURE WITH MAXIMUM DEFLECTION IN THE BOX COMPRESSION TEST

	Deflection, inch									
	Sample 2406	Sample 2407	Sample 2408	Sample 2430	Sample 2456	Sample 2457	Sample 2497	Sample 2498	Sample 2510	Sample 2511
Max. deflection (box compression test), inch	0.59	0.64	0.67	0.61	0.44	0.93	0.38	0.45	0.45	0.35
Creep failure defl., inch[a]										
0.75 load ratio										
1	0.64	0.62	0.73		0.44	0.84		0.42	0.45	0.38
2	0.65	0.71	0.78		0.39	1.02		0.49	0.48	0.35
3	0.56	0.61	0.73		0.39	1.06		0.45	0.62	0.33
4	0.59	0.54	0.76		0.37	1.13		0.54	0.44	0.37
Av.	0.61	0.62	0.75		0.40	1.01		0.48	0.50	0.38
0.70 load ratio										
1	0.65	0.67			0.51	1.06	0.41	0.51		0.35
2	0.66	0.69			0.46	0.96	0.41	0.54		0.37
3	0.67	0.67			0.43		0.40	0.50		0.35
4	0.58	0.69			0.53		0.40	0.50		0.39
Av.	0.64	0.68			0.48		0.40	0.51		0.36
0.675 load ratio										
1	0.69	0.77								
2	0.66	0.70								
3	0.61									
4	0.54									
Av.	0.62									
0.625 load ratio										
1	0.63	0.67	0.62	0.61	0.44	0.99	0.38	0.58		0.33
2	0.63	0.56	0.77	0.68	0.49	--	0.38	0.48		0.36
3	0.70	0.68	0.74	0.61		0.95	0.43	0.52		
4	0.66	0.64	0.76			1.05	0.42	0.52		
Av.	0.66	0.64	0.72				0.40	0.52		
0.575 load ratio							0.44			
0.55 load ratio										
1	0.60	0.63	0.78							
2	0.58	0.78	0.74							
3	0.54		0.76							
4	0.64									
Av.	0.59									
0.50 load ratio										
1		0.66								
2		0.74								
3		0.75								
Av.		0.72								

[a]The creep failure deflection is defined as the last recorded value of the box deflection prior to box collapse.

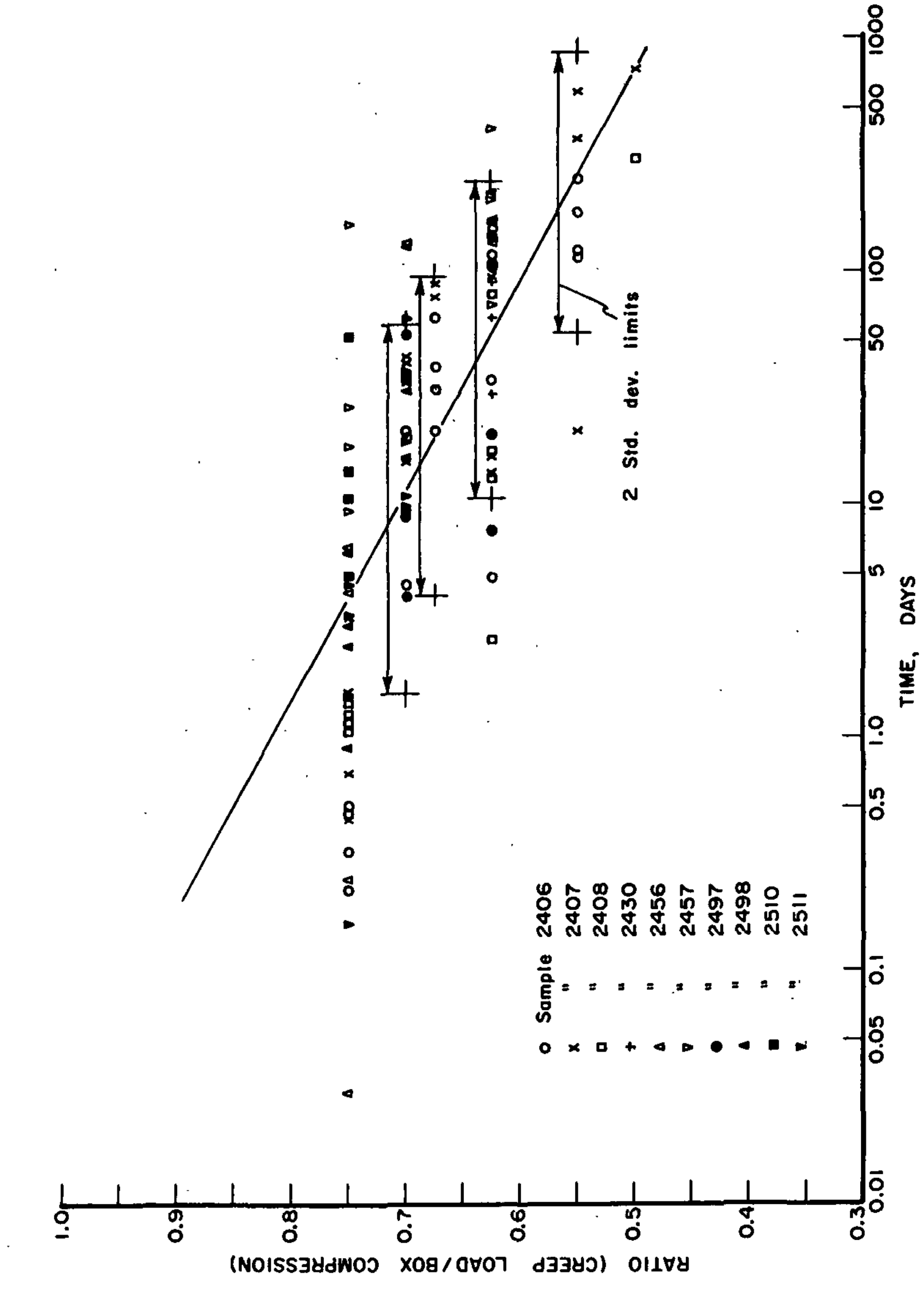

Figure 1. Relationship between Failure Life and Applied Load.

TABLE III

BOX FAILURE LIFE

Load Ratio	Box Failure Life, days: Fig. 1	Kellicutt & Landt[a]
0.75	4.0	0.6
0.70	11.5	2.0
0.675	18.5	3.6
0.65	32	7
0.625	54	14
0.600	92	25
0.55	260	86

[a] From Reference (1).

To supplement the above, the available box results at load ratios of 0.625, 0.70 and 0.75 were subjected to an analysis of variance to determine if the various box samples exhibited significantly different stacking lives. The analysis was carried out using stacking times expressed in (1) days and (2) transformed to logarithms. The logarithmic analyses are believed to be more appropriate because (a) the logarithm of the failure time is believed to be related to the load ratio and (b) the wide deviations in the individual data suggest that badly skewed distributions are obtained.

The box data used in the analyses are shown in Table IV. At each load ratio an analysis of variance was carried out to determine if significant differences between samples occurred. Tukey's gap test procedure was then used to determine which of the samples exhibited significantly different stacking times. The following results were obtained:

1. At 0.75 load ratio, Sample 2457 exhibited a significantly longer stacking

TABLE IV

BOX RESULTS USED IN ANALYSIS OF VARIANCE

Sample No.	Flute	Series	Perimeter, in.	Top-Load Compression		0.75 Load Ratio		0.70 Load Ratio		0.625 Load Ratio	
				Load, lb.	Defl., in.	Arith., Av.	Log Av.	Arith., Av.	Log Av.	Arith., Av.	Log Av.
2406	A	200	56.5	940	0.59	0.38	0.36	78.7	26.3	77.5	40.9
2407	A	200	77.0	975	0.64	12.13	2.62	32.7	30.4	54.8	37.4
2408	A	200	94.0	1180	0.67	1.20	1.20	--[b]	--[b]	28.0	14.5
2456	A	175	39.8	555	0.44	2.72	0.66	--[b]	--[b]	--[b]	--[b]
2457	C	350	50.0	1235	0.93	51.60[a]	28.54[a]	--[b]	--[b]	--[b]	--[b]
2510	C	275	56.0	960	0.45	19.94	13.74[a]	--[b]	--[b]	--[b]	--[b]
2497	B	200	51.2	665	0.38	--[b]	--[b]	19.0	11.6	67.4	38.4
2498	B	275	67.8	970	0.45	3.14	2.55	53.4	39.9	221.5[a]	217.6[a]
2511	B	175	51.5	525	0.35	2.42	1.39	10.8	9.3	--[b]	--[b]

a Significantly different at the .05 level.

b Testing incomplete.

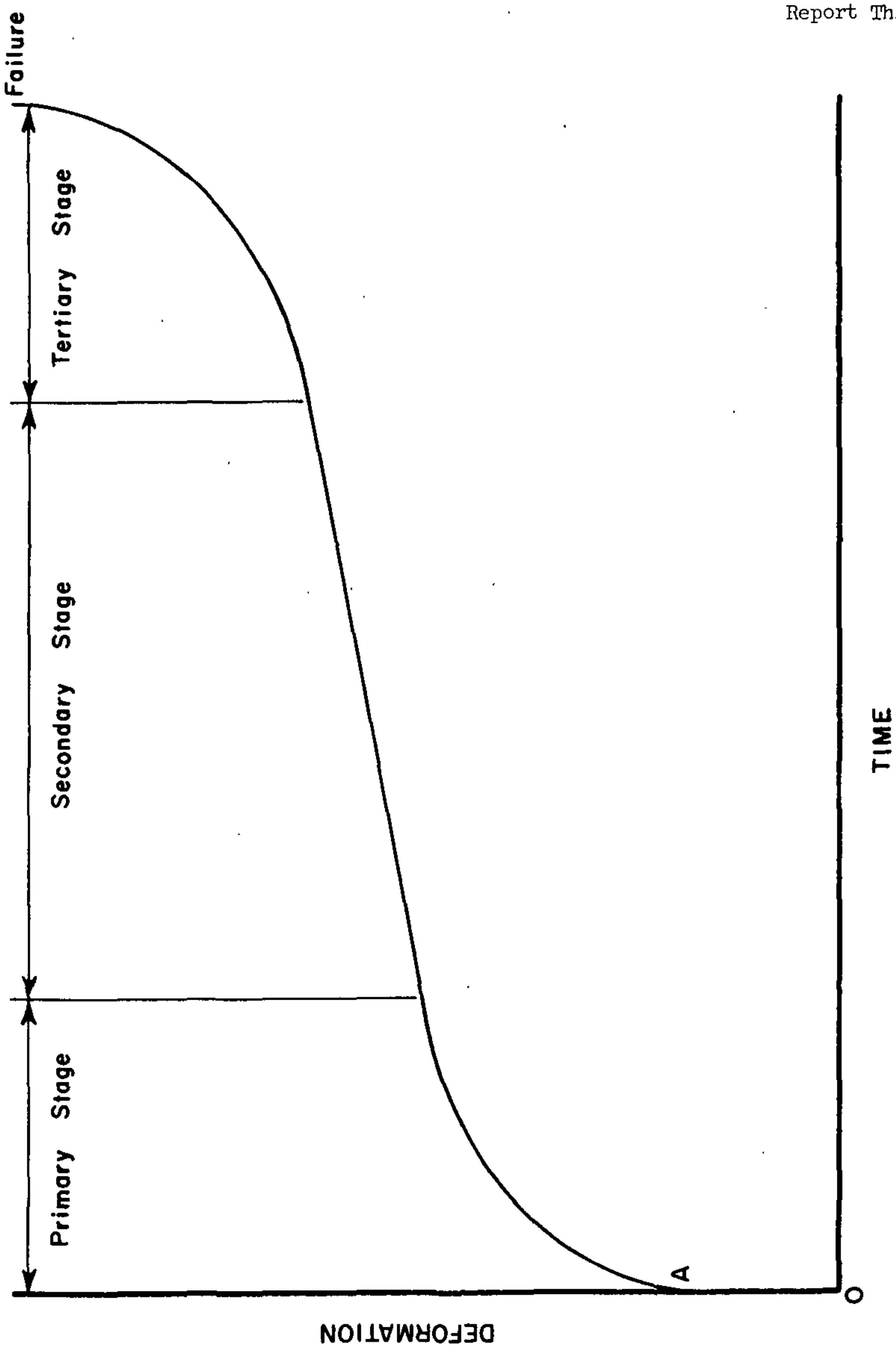

Figure 2. Idealized Creep Curve

life in the arithmetic analysis. In terms of logarithms, Samples 2457 and 2510 exhibited significantly longer lives. While the data for these samples are not complete at lower load ratios (in part because of their long survival times), it appears that Sample 2457 will exhibit long stacking times at both 0.70 and 0.625 load ratios (see Table I). In the case of Sample 2510, there are insufficient data at the lower load ratios to make any projections at this date.

2. At 0.70 load ratio, the five box samples available for analyses did not exhibit a significant difference in stacking time.

3. At 0.625 load ratio, the 275-lb. test B-flute sample (2498) exhibited a significantly longer stacking life than the other samples. This sample exhibited a relatively long life at 0.70 load ratio; however, its stacking time at 0.75 was about average.

While the data are limited, therefore, there is some evidence that certain commercial boxes exhibit significantly longer stacking lives at constant load ratio. The differences can be quite large. For example, Sample 2408 gave an average stacking life at 0.625 load ratio of 28.0 days while Sample 2498 survived 221.5 days on the average. The shortest stacking lives for these same samples were 2.6 and 160.4 days.

If the reasons for the variability in stacking life within and between box samples were known, it should be possible to effect an improvement in box stacking life.

Deflection *Vs*. Time

During a box stacking test the scorelines and sidewalls gradually deform. Much of the total deflection is associated with crushing of the scorelines. Failure occurs as the deflection nears the deflection attained in the box compression test with the important difference that the deflection goes to infinity in the box stacking test as failure occurs.

An idealized creep curve is shown in Fig. 2. In general, the initial deflection and the rate at which deflection occurs in the secondary and tertiary stages will vary from box-to-box and lot-to-lot under a given set of conditions.

In Report Two, efforts were made to develop empirical equations to fit the box deflection vs. time curves. Thus, if the path of such curves could be predicted from short term tests, estimates of failure time could be made.

Equations of the following type were studied in Report Two:

$$\text{Log } t = \text{Log } K_1 + K_2 \text{ Log } (D - D_6) \qquad (1)$$

where

t = time

D = deflection at time t

and K_1, K_2 and D_6 are constants

Reasonably good fits to the curves were obtained by setting the deflection at 60 minutes equal to D_6. To be useful, however, it was noted that the regression constants must be constant for most combined board constructions or must vary in some predictable way with the applied load ratio and short term tests.

In this connection, D_6 is a measure of the initial deformation and should be related to the applied load ratio and the maximum deflection in the conventional compression test. To investigate this possibility, the box deflections at 60 minutes (D_6) in the stacking tests were divided by the box compression deflection (D_f) at maximum load. The available results are shown in Table V and graphed vs. the load ratio in Fig. 3. It is evident that the relationship between these quantities was

TABLE V

BOX DEFLECTION AT 60 MINUTES

Sample No.	D_6/D_f						
	0.50 LR	0.55 LR	0.575 LR	0.625 LR	0.675 LR	0.70 LR	0.75 LR
2406		0.789		0.879	0.904	0.954	0.940
2407	0.730(3)			0.749	0.885(2)	0.887	0.846
2408				0.914			1.044
2430 [a]							
2456			0.735(3)	0.807		0.836(2)	0.833(3)
2457				0.729(3)			0.905
2510 [a]							
2497				0.885		0.953	
2498				0.815		0.856	0.900
2511						1.015	1.099

[a] No available data.

Note:

D_6 = Box deflection at 60 minutes

D_f = Box deflection at maximum load in conventional compression test

LR = Load ratio

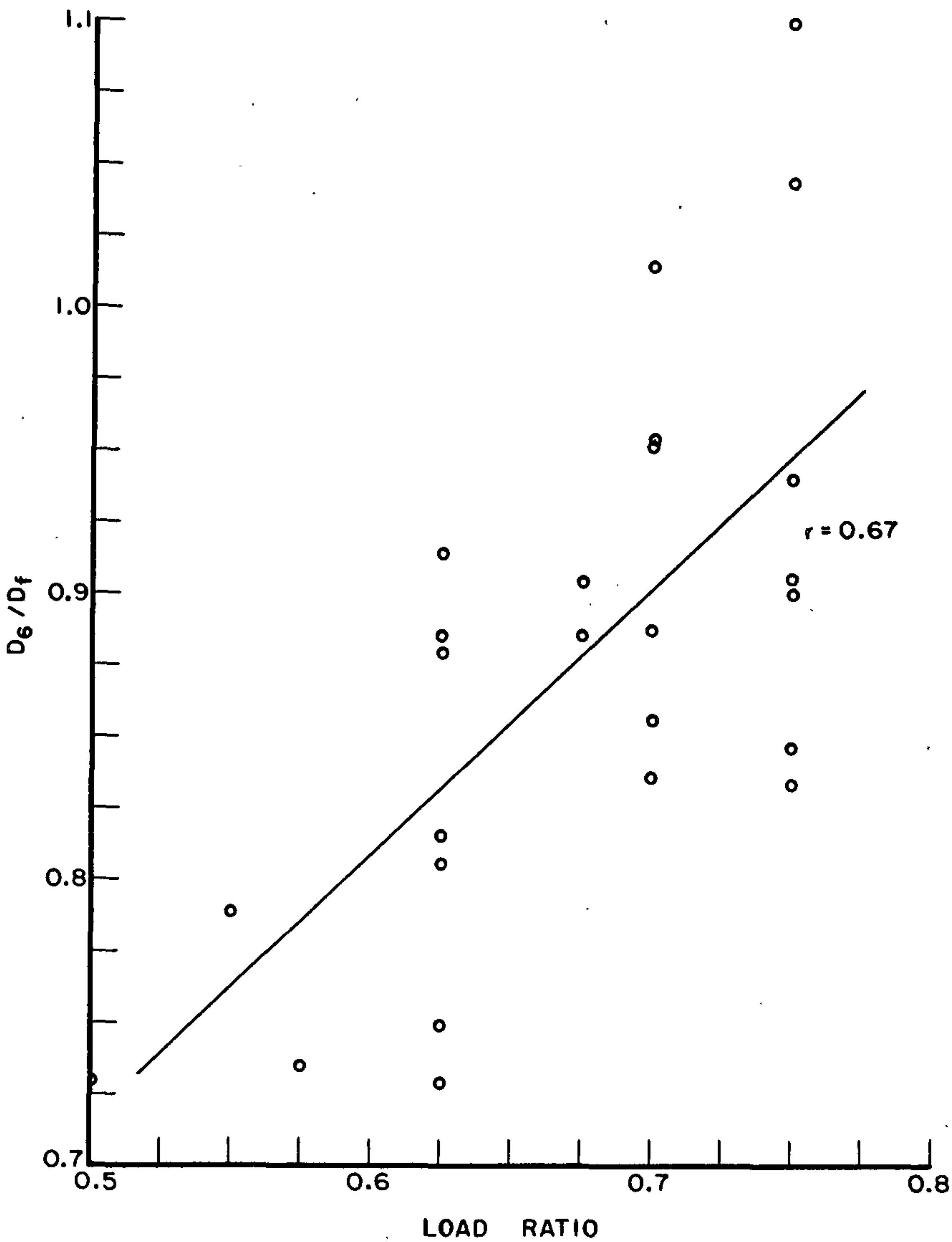

Figure 3. Relationship between D_6/D_f and the Applied Load Ratio

only fair. The regression line had a correlation coefficient of 0.67 and its equation was as follows:

$$D_6/D_f = 0.259 + 0.917\ R \qquad (2)$$

where D_6 = box deflection at 60 minutes

D_f = box deflection at failure in box compression test

R = applied load ratio

To investigate the utility of this approach, the stacking results for Sample 2406 were investigated in detail. Using Eqt. (2), predictions of D_6/D_f were made for each load ratio and D_6 was then calculated. These values of D_6 were then used to obtain regression equations having the form of Eqt. (1) for each box at each load ratio. In addition, at each load ratio, a composite regression line (CRL) was obtained as well as an equation obtained using a covariance technique.

The results are shown in Table VI. It may be noted that at constant load ratio, the constants varied widely from box-to-box. Predictions of failure life were also quite poor. Further work is needed to improve the prediction accuracy. This may involve study of other functions or additional adjustments in the use of Eqt. (2). For example, in Table II the deflections near box failure in the creep tests tend to be slightly greater than the conventional box compression deflections. An upward adjustment of the critical box deflection would considerably improve the predictions in Table VI.

Literature Cited

1. Kellicutt, K. Q. and Landt, E. F. Forest Products Laboratory Report No. 1911. September 1958.

2. Tukey, J. W. Biometrics. Vol. 5 (1949); p. 99-114.

TABLE VI

DEFLECTION VS. TIME REGRESSION EQUATIONS FOR BOX 2406

Identification	D_6	N[a]	Regression Constants[b] Intercept	Regression Constants[b] Slope	R	Stacking Life, days: Observed Max.	Observed Min.	Observed Av.	Predicted	Diff.
				0.55 Load Ratio						
Box 4-1	0.450	44	3.89079	1.49979	0.986	--	--	174.4	408	+223.6
Box 1-2		46	6.71057	5.41464	0.983	--	--	113.3	122	+ 8.9
Box 2-3		46	5.17188	3.32442	0.980	--	--	114.5	215	+100.5
Box 3-4		69	5.40790	3.87065	0.980	-	--	243.6	127	-116.6
Comp. reg. line (CRL)		205	2.94983	1.28458	0.524	243.6	113.3	161.4	71	- 90.4
CRL minus box 4-1		161	4.93890	3,37269	0.903	243.6	113.3	161.4	115	- 46.4
Covariance line (CVL)		205	4.97052	3.08069	--	243.6	113.3	161.4	173.8	+ 12.4
				0.625 Load Ratio						
Box 1	0.491	26	4.13399	2.82496	0.989	--	--	33.8	19.8	- 14.0
Box 2		7	4.18915	3.94868	0.985	--	--	4.8	1.7	- 3.1
Box 3		59	5.55217	4.25109	0.970	--	--	155.7	19.2	-136.5
Box 4		35	5.61961	4.27143	0.983	--	--	115.4	21.4	- 94.0
CRL		127	5.00488	3.70517	0.904	155.7	4.8	77.4	19.2	- 58.2
CVL		127	4.95838	3.65839	--	155.7	4.8	77.4	20.0	- 57.4
				0.675 Load Ratio						
Box 1	0.518	11	4.96835	4.22860	0.947	--	--	30.5	1.4	- 29.1
Box 2		20	5.66631	4.49324	0.973	--	--	62.1	3.4	- 58.7
Box 3		13	4.98382	3.10574	0.989	--	--	38.4	27.2	- 11.2
Box 4		3	--	--	--	--	--	20.4	--	--
CRL minus box 4		44	3.53418	2.27633	0.759	62.1	20.4	37.8	8.6	- 29.2
CVL minus box 4		44	5.04474	3.70696	--	62.1	20.4	37.8	6.4	- 31.4
				0.700 Load Ratio						
Box 1	0.532	108	5.18213	2.89072	0.976	--	--	270.6	40.5	-230.1
Box 2		9	7.28515	6.52166	0.975	--	--	19.6	0.2	- 19.4
Box 3		10	7.84542	7.49984	0.973	--	--	20.0	0.04	20.0
Box 4		2	--	--	--	--	--	4.5	--	--
CRL minus box 4		127	3.60316	1.64519	0.374	270.6	4.5	78.7	37.0	41.7
CVL minus box 4		127	5.17684	3.10612	--	270.6	4.5	78.7	21.7	57.0

[a] The number of data points after discarding negative values of $D-D_6$ and time values less than 0.1 day.

[b] Regression equation: $\text{Log } t = \text{Log } K_1 + K_2 \text{ Log } D - D_6$.